Lunar and Planetary Information
BULLETIN

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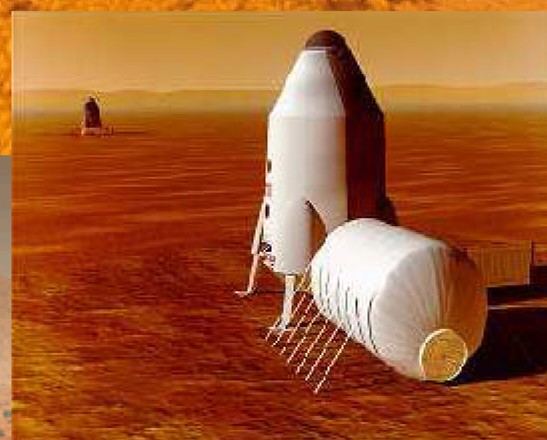
Exploring Mars

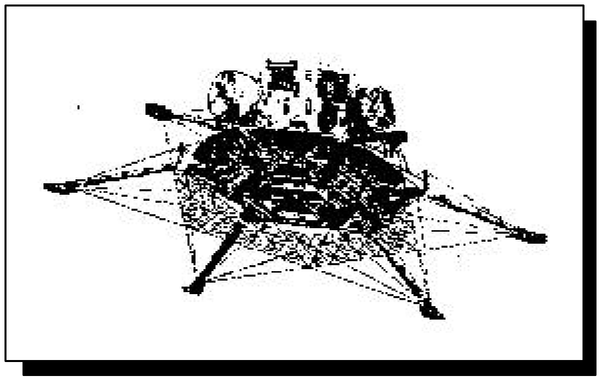
Concepts and Approaches



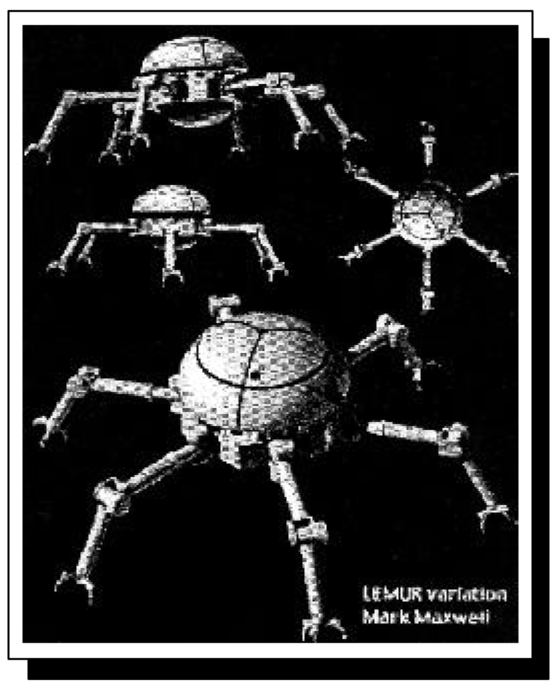
CONTENTS

DESTINATION. . . MARS

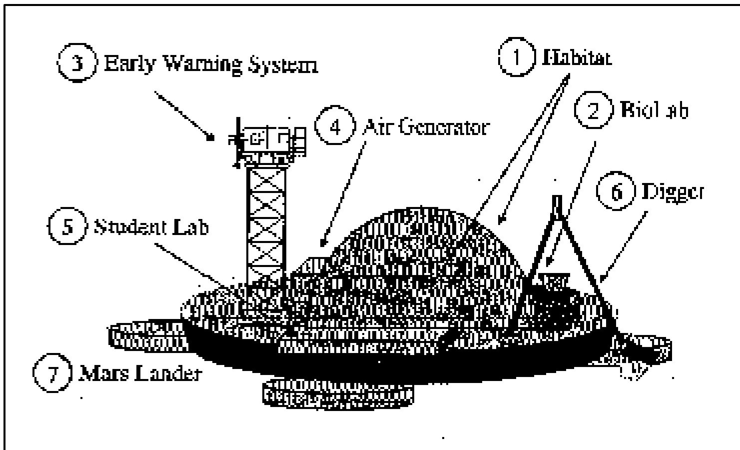
During the last year of this millenium, on July 18–20, 2000, the Lunar and Planetary Institute hosted a workshop entitled Concepts and Approaches for Mars Exploration, to facilitate discussion on possible approaches for the exploration of Mars' surface and atmosphere on future missions. The workshop, co-sponsored by LPI and NASA Headquarters and convened by Scott Hubbard, attracted more than 150 registered participants and more than 130 abstracts. What follows is a sampling of some of the conceptual images presented at that workshop. The images demonstrate a marked optimism about the possibilities for martian exploration while solidifying and advancing some very real scientific ideas. The full abstracts for the meeting are available online.



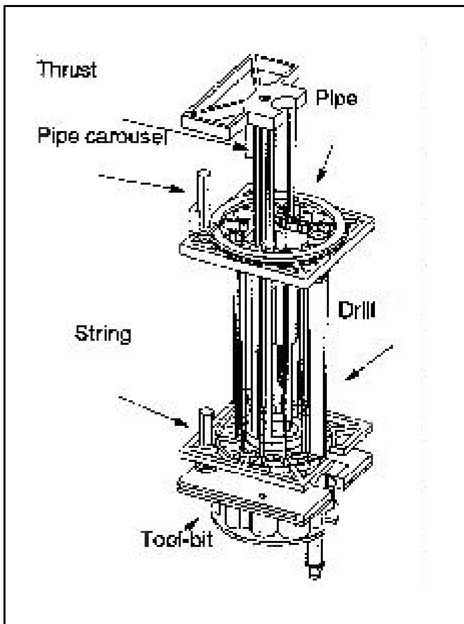
(Left) Bottom isometric view of a "pallet lander" that would be used for landing in extreme terrain. The outriggers help to prevent tipover. (Rivellini et al.)



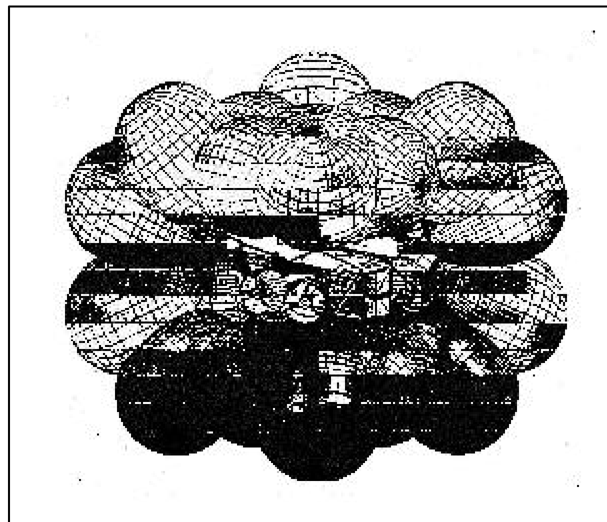
(Right) Task-adaptive walking robots are currently being designed in a variety of configurations. This model features a hexagonal body. Most of the designs being considered emphasize mobility in cooperation with autonomous navigation and the ability to manipulate objects with certain legs while maintaining stability on the others. (Huntsberger et al.)



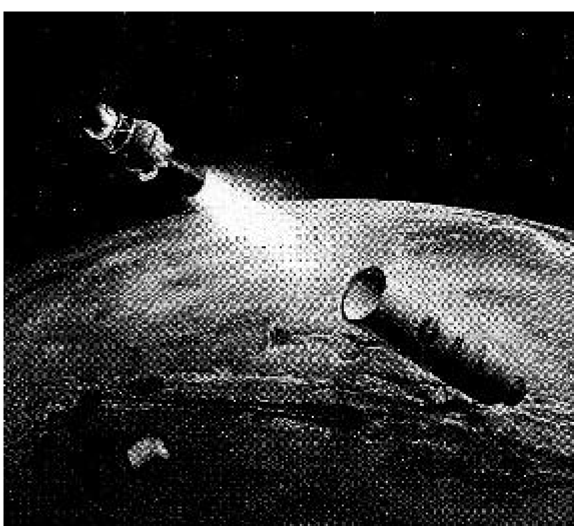
(Left) MarsLab lander concept as conceived by the Human Exploration and Development of Space program. The habitat includes an inflated dome with controlled atmosphere and thermal management, and would be maintained by an air generator and greenhouse technology. (Hecht et al.)



(Left) Drilling and sampling subsystem designed to accompany the Nonkhod microrover, developed most recently with the frame of the European Space Agency's Technology Research Program. (Bertrand et al.)



(Above) Isometric view of an airbag landing system, with two bags removed for the purposes of illustration. The lander would allow for the safe landing of a rover on extreme terrain. (Rivellini et al.)



(Left) Launch vehicle as envisioned by the Orbital Sciences Corporation for NASA's JPL's Mars Ascent Vehicle study in 1999. The booster allows the return of samples from the martian surface to orbiting spacecraft. (Dorsch et al.)

About the Cover Images

The futuristic image of the Mars Airplane was conceived by Bill Kluge and Larry Merrill, NASA Langley Research Center. The other two images include the proposed Mars 2003 rover, Jet Propulsion Laboratory, and an artistic conception of a possible Mars base, courtesy NASA. The background is a recent *Mars Global Surveyor* image.

POLICY IN REVIEW

The following letter, directed to Jay Bergstralh of NASA Headquarters, presents the findings of the Solar System Exploration Subcommittee of the Space Science Advisory Committee, which met during October 2000 to discuss the future of solar system space exploration. Dr. Michael J. Drake, chair of that committee, has submitted this letter to this forum for public review.

November 27, 2000

Dr. Jay Bergstralh
Code S
NASA Headquarters
Washington, DC 20546

Dear Jay:

The Solar System Exploration Subcommittee (SSES) of the Space Science Advisory Committee (SScAC) met on October 30 and 31, 2000, in Pasadena, California. The purpose of this letter is to summarize the findings and recommendations of that meeting.

Mars Exploration

The SSES received reports from Scott Hubbard, Jim Garvin, and Farouz Naderi. It is clear to the SSES that NASA has put its "A Team" in charge of the Mars Exploration Program, and overwhelmingly endorses the missions set laboriously constructed after consultations with a wide range of constituencies. Given budget constraints, the team has done an excellent job. A minority view felt the plan was "timid" in that it did not obviously engage enough public support and may be inconsistent with a possible future decision to send humans to Mars in the next decade.

Antarctic Meteorites

The SSES noted that one way to increase access to martian samples for fairly low cost is to increase the recovery rate of martian meteorites. Currently, martian meteorites from Antarctica account for approximately 1 in 2000 Antarctic meteorite specimens, or a recovery rate of about 1 every 4 years. For an investment of ~$400K–450K per year (or 0.02% of the currently projected cost of a Mars sample return mission), predominantly for field logistics and curation support, the rate of Antarctic meteorite recovery could be approximately doubled. This would be accomplished by putting a second field team on the ice each season, either in a reconnaissance mode (investigating new regions to assess their suitability for future collecting seasons) or collecting mode (systematic searching for meteorites in one or more areas). The consensus of the SSES is that this moderate investment from the Mars Program budget could go a long way to preparing us to handle and analyze returned martian samples, but should not be construed as a substitute for returning a scientifically selected suite of samples from Mars in the near future. The SSES recommends that investment in increasing the recovery rate of martian meteorites be made.

Outer Planets

The highest-priority outer planet missions, *Pluto-Kuiper Express* (PKE) and *Europa Orbiter* (EO), have received strong endorsements in previous considerations by COMPLEX and SSES. Recent developments in our understanding of the solar system have strengthened the case for both of these missions as a compelling and essential part of NASA's planetary program. This is documented below. There is no compelling scientific basis for a program that places EO ahead of PKE in importance. An orderly and timely program that accomplishes these missions takes advantage of the 2004 launch opportunity for PKE. The likely delay in EO that is implied by this choice is unfortunate but vastly preferable to the alternative of a long delay and possible associated degraded science of PKE. Given the difficulty in solving EO engineering problems before 2006 at the earliest, it is logical to consider flying PKE first. EO would still return data first.

PKE is a pioneering mission. It takes us to examples of an important and little understood class of bodies, the small icy objects that populate the Kuiper Belt. In our developing understanding of these bodies, we have come to recognize that they are essential to our understanding of how planets form and what materials go into habitable planets, including Earth. The giant planets define the architecture of our solar system, define the inner edge of the Kuiper Belt, and probably determined the delivery of much of the most volatile materials including water to planet Earth. In the Kuiper Belt bodies, the largest known example of which is the planet Pluto, we have repositories of volatile and organic matter and information on the mass and distribution of materials dating back to solar system origin. We need to learn about compositions, and about the population of bodies expressed through impact cratering of the surfaces of these bodies. These goals are central aspects of NASA's Origins Program.

We must go there. The information needed is mostly unobtainable from telescopic observations, even allowing for future improvements. Though small, Pluto has an atmosphere and is expected to have internal dynamic processes. The Pluto-Charon binary planet system has no other solar system analog in its tidal evolution except possibly Earth and our companion the Moon. The images from the Pluto encounter, collected over an extended period, are likely to fascinate the public. From our perspective close to the Sun, this is a mission to the frontier of the solar system, an appealing aspect to both scientists and the public.

The scientific justification for EO remains strong. *Galileo* results have strengthened the case for a water ocean but have led to no consensus about ice thickness or the conditions beneath the thin, outermost brittle layer of very cold ice. A well-instrumented EO should be designed to answer with certainty the issue of whether there is an ocean and identify some aspects of the nature of this subsurface environment that might support life. An orderly approach to Europa exploration calls for an orbiter before a lander. However, there is no aspect of our developing view of Europa that would compel us to place its importance above that of the science addressed by PKE.

The SSES received a presentation from Lockheed Martin that suggested that different PKE concepts could possibly achieve scientific objectives at lower cost than the current PKE baseline mission.

The consensus of the SSES is that JPL should be given until approximately the end of November 2000 to formulate a plan that achieves EO and PKE within the current budget. If they are unable to come up with a solution PKE, and possibly EO, should be put out for competitive bidding through an appropriate process.

If such a plan is followed and JPL is unable to come with a viable plan, the recommended boundary conditions are:

a. NASA announce selections of the PKE and EO science payloads by January 2001 from those that have been proposed in response to the September 10, 1999 AO (AO-99-OSS-04).

b. AO solicitation be issued by NASA on or before January 15, 2001, requesting proposals that include the totality of the OP program, *a la* Discovery, and accommodate the NASA-selected science payloads. Responses should be requested by April 15, with intended NASA selection by June 1, 2001.

c. Simultaneously with the issuance of the AO, NASA should proceed to begin manufacture of an appropriately sized RTG (e.g. RTG9), with currently existing hardware. Also, NASA should initiate processes for regulatory approval of a PKE launch no earlier than December 2004.

The above recommendations will accomplish a number of Outer Planets science and programmatic objectives. These include timely launch of a PKE mission to take advantage of the unprecedented opportunity in the 2004 launch window, within a possibly affordable budget; continued development of EO technology for a launch in the 2005–2010 timeframe that will result in returned science data from Europa long before the PKE flyby of the Pluto-Charon system; and likely implementation of the program within NASA budgetary guidelines, with appropriate adjustments.

Attached Payloads

The SSES considered the problem of the suborbital/attached payloads program that has found itself fitted within the Planetary Atmospheres program as an unfunded mandate. For FY00 that amount is $300K out of the $8M Planetary Atmospheres budget. It was widely agreed that level of funding is far below any reasonable support level for the program and that the mandate must necessarily grow to $450K in FY01 and $600K in FY02. The consensus of the SSES is that if that program support remains within Planetary Atmospheres, it should continue to be separated by a firewall from the rest of Planetary Atmospheres. The two programs are distinctly different in terms of their average grant size (about a factor of 2) and in their objectives (basic investigator science vs. flight missions, technology development, space hardware training). The SSES sees as the most important objective to find a natural home for the planetary suborbital/attached payloads program, perhaps as a new, free-standing Research and Analysis Program for suborbital/attached payloads that cuts across themes. This would allow SSE proposals to compete more directly with their naturally complementary counterparts from other themes. The financial support at the current or projected level from the SSE suborbital grants would be contributed to this program. This kind of cross-theme program is not unprecedented. Such a program currently exists in the Flight Information Systems area. The SSES recommends that the SScAC review the suborbital/attached payloads issue to advise on the possibility of creating a cross-theme program. The availability of the Space Shuttle and the International Space Station should not be overlooked by the Solar System Exploration Program.

Cassini

The failure to account adequately for the Doppler shift between *Cassini* and the Huygens probe was discussed. It appears that there are solutions related to mission operations that can compensate for this oversight. The SSES recommends that any solution maximizes overall mission science return, even if it involves delaying deployment of the Huygens probe.

Deep Space Network

The SSES received a briefing that points to a significant overload of DSN capabilities in 2004 and beyond, but measures are being followed to mitigate this problem. The Solar System Exploration Division should nevertheless remain concerned that an adequate solution is achieved.

Planetary Data System

It appears the PDS is underfunded by about $2M per year. The Solar System Exploration Program needs to address this issue.

MUSES-CN

MUSES-CN is a Japanese mission to an asteroid to carry out *in situ* science and return samples to Earth. The SSES concurs in NASA's decision to terminate its involvement in the rover program. It is critical, however, that NASA assures access to samples for U.S. scientists.

With kindest regards.

Sincerely,

Michael J. Drake, Chair
Solar System Exploration Subcommittee

NEW IN PRINT

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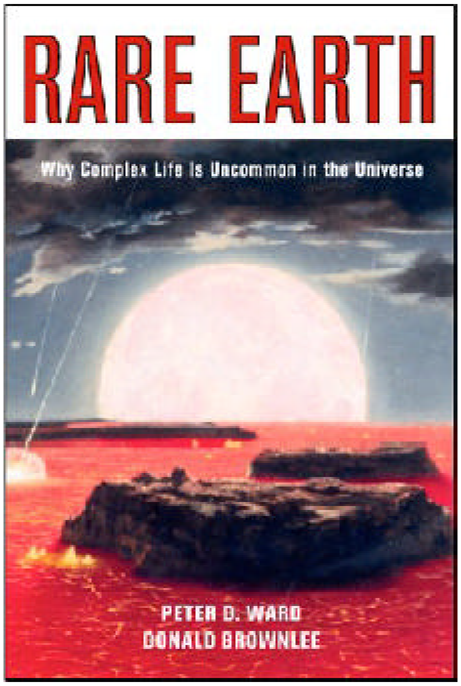


REVIEW

RARE EARTH: Why Complex Life is Uncommon in the Universe
by Peter D. Ward and Donald Brownlee
334 pages
Springer-Verlag, 2000

The polemical title of Ward and Brownlee's controversial book belies its careful, detailed approach to the age-old question of whether man is alone in the universe. The authors' conclusion, however, remains startling and even argumentative: While life on the microbial level may be common in the universe, intelligent, complex life is probably rare.

Centuries and even decades ago, such an argument would have been framed in philosophical terms; to argue that man as an intelligent creature was alone in the universe reinforced the idea that man was unique and central to the purpose of the universe. Today, the argument has shifted to scientific ground, with the philosophical implications seeming to have more import on the pro-extraterrestrial side: i.e., the conclusion that man is man is truly alone may be too bleak, too unimaginative of a prospect to face.

A casual, side-by-side comparison of *Rare Earth* with any number of pro-E.T. arguments from the past sheds light on the weaknesses of the assumptions of those arguments. The conclusion that life is startlingly common in the universe, an idea built on the foundation of the Drake equation and most vocally supported by Frank Drake and Carl Sagan (to whom the book is dedicated), derives much of its strength from the supportive argument that where life could arise, it would. This idea is based almost exclusively on the famous experiments of Harold Urey and Stanley Miller in the 1950s that successfully created amino acids in laboratory conditions.

Ward and Brownlee argue that the research of the past 40 years has not exactly borne out the optimistic conclusions of those famous experiments. Whereas those experiments showed how the building blocks of life could be created in laboratory conditions, the challenge of creating DNA artificially has proved more daunting. Such organic molecules, the authors point out, tend to break down when heated, making the presence of a moderate temperature vital. In addition, in the absence of a reducing atmosphere, as has been argued by Everett Shock and others, the most likely spot for the origin of life would have been hydrothermal vents, which would seemingly deflate Miller and Urey's dramatic scenario of lightning striking the early ocean to create organic compounds.

Similarly, those in the Drake camp often argue that intelligent life will naturally arise where complex life has taken root. This assumption is usually predicated on the still-uncertain assertion that Earth has given rise to more than one intelligent species. Yet many of the dramatic studies purporting to show the sociability and communicativeness of such species as dolphins and chimpanzees remain shrouded in mystery and political misgiving. Do animals imitate communication in order to please their human caretakers, or do we see patterns of communication because of our collective wish to relate to other species?

While the optimistic assumptions of such luminaries as Drake and Sagan certainly have philosophical value, and scientific value in as much as they have spurred discussions of the factors necessary for life to arise, they lack the hard evidence that scientists traditionally rely upon. Yet Ward and Brownlee do not simply pose as nay sayers,

Lowell Observatory

Percival Lowell's map of the "canals" on Mars.

attacking the arguments of the "pro-E.T." world view. Rather, the authors attempt to alter the debate by changing the fundamental approach. Instead of starting with a mysterious equation and attempting to fill in the unknown blanks, they begin with what we know about life and the Earth itself, and build upward.

As Ward and Brownlee argue, it is not any one factor that is particularly rare about Earth, but rather the coagulation of so many relatively unusual traits: the Earth formed in a galaxy around a star rich in metal and located in a safe region of a spiral galaxy; this star is not part of a binary system, and is not near any active gamma-ray source; the presence of gas giants in our own solar system prevented our Earth from being too heavily bombarded by asteroids and comets; and relatively constant global temperatures allowed Earth to maintain liquid water for more than 4 billion years.

Perhaps the most important factors in giving rise to intelligent life, the authors suggest, are the presence of a large Moon and the influence of plate tectonics. The Moon in particular may be more vital to our survival than we have possibly imagined, by helping to regulate the obliquity of the Earth's angle of axis, and therefore helping to keep surface temperature consistent. Of the four terrestrial planets, Earth alone has such a relatively large Moon, which is believed to have formed from a collision with a Mars-sized body sometime during the Earth's early formative stages. Such an event must be held to be uncommon, if not rare. Similarly, the presence of plate tectonics, also found only on Earth thus far, has allowed our planet to regulate its global temperature via the relative mix of carbon dioxide, and to promote biodiversity, thus protecting against mass extinction.

While not a highly technical book, *Rare Earth* will appeal mostly to readers with a broad scientific background and an astute interest in the search for life elsewhere. Exobiologists and other specialists, while they will likely value the book for its thesis, may find some of the book's background explanations, such as the explanation of the steps necessary for creating DNA, too elementary, while strictly lay readers may find the discussions of "reducing atmospheres" and other such topics somewhat confounding.

The final chapter of *Rare Earth* turns briefly from its scientific argument to mourn the increasingly rapid loss of biodiversity on our own planet. If animal life is indeed rare, the authors point out, the tragedy of species extinction on Earth is all the more tragic. While this final, solemn plea may jar readers who have otherwise found the scientific tone of this book refreshing, it serves as a reminder that it is difficult to completely avoid philosophical questions in this arena. More than anything, perhaps, the collective desire to be rescued from above may not easily be put to rest, because a resounding "no" to the question of whether we are alone squarely shifts the responsibility for the future of the human race back on the shoulders of humans themselves.

— Brian Anderson

(Brian Anderson is the editor of the Lunar and Planetary Information Bulletin.)

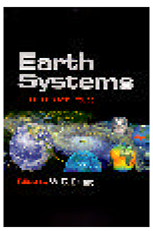
NEW IN PRINT

RECENTLY PUBLISHED

Comet Science: The Study of Remnants from the Birth of the Solar System. By Jacques Crovisier and Therese Encrenaz. Cambridge Univ. Press, 2000, Hardback, $54.95, Paperback, $19.95. Provides a survey of the study of comets throughout history, and discusses the most recent discoveries on the celebrated Comets Hale-Bopp and Hyakutake.

Stellar Rotation (Cambridge Astrophysics Series). By Jean-Louis Tassoul. Cambridge Univ. Press, 2000, Hardcover, $69.95. This reference and survey volume is part of the Cambridge Astrophysics Series.

Solar and Stellar Magnetic Activity (Cambridge Astrophysics Series). By Carolus J. Schrijver and Cornelis Zwaan. Cambridge Univ. Press, 2000, Hardcover, $80. Part of the Cambridge Astrophysics Series, this volume provides a review of the current knowledge of the origin, evolution, and effects of magnetic fields in the Sun and other cool stars.



Earth Systems: Processes and Issues. Edited by W. G. Ernst. Cambridge Univ. Press, 2000, Softcover, $44.95. Comprehensive textbook designed for introductory courses in Earth systems science and environmental science.

Apollo 13: NASA Mission Reports. Apogee Books, 2000, Softcover, $16.95. This latest volume in the reprint series from Apogee Books includes the original press releases, technical reports, and reports on the hearings that investigated the causes of the accident that forced the astronauts to abort the original mission and take emergency steps to return home safely. Includes a CD with flight-related footage and images.

Mars: NASA Mission Reports. Apogee Books, 2000, Softcover, $21.95. Collects the techincal reports and other relevant documents from all the NASA Mars missions to date, including the Viking, Mariner, Pathfinder, Global Surveyor, Climate Orbiter, and Polar Lander missions. The accompanying CD-ROM features hundreds of still images, animations, and a 360-degree Quicktime panorama from Mars Pathfinder.

Science Blundering: An Outsider's View, Second Edition. By Herbert L. Nichols, Bellemore Books, 2000, Hardcover, $15.

Magnetic Reconnection: MHD Theory and Applications. By Eric Priest and Terry Forbes, Cambridge University Press, 2000, Hardcover, $80. Presents an overview of the process behind such dramatic phenomena as solar flares and geomagnetic substorms. Appropriate as an introductory text for graduate students or as a reference for researchers.

Protostars and Planets IV. V. Mannings et al., eds. University of Arizona Press, 2000, Hardcover, $95. An update of a previous version published in 1993, this latest volume in the venerable Space Science Series brings together 167 authors reporting on the most significant advances in star and planet formation research.

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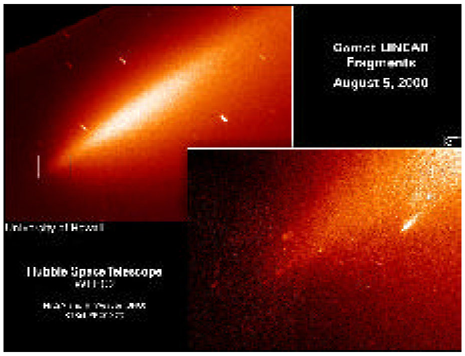


STSCI

Astronomers working with the Hubble Space Telescope have identified pieces of the explosive Comet LINEAR.

HST Discovers Missing Pieces of Comet

To the surprise of astronomers, NASA's Hubble Space Telescope has discovered a small armada of "mini-comets" left behind by what some astronomers had assumed was a total disintegration of the explosive Comet LINEAR.

Hubble's discovery has settled the fate of the mysteriously vanished solid nucleus of the comet, which seemed to disappear after it moved around the Sun.

On July 27, groundbased observers lost sight of the bright core of the comet and suggested that the nucleus disintegrated into a pile of dust. Astronomers at the Space Telescope Science Institute in Baltimore, Maryland, quickly reprogrammed Hubble to search for the missing nucleus.

Johns Hopkins University astronomer Hal Weaver said he was stunned when the Hubble image first appeared on his computer screen.

"My first thought was Hubble Space Telescope does it again," he said. "This is amazing."

Although comets have been known to break apart before, this is the first time astronomers have had a close-up view of the dismantling of a comet's nucleus due to the Sun's heat. Since the 1950s, researchers assumed comet nuclei were loose clusters of ice and dust, called cometesimals, held together by gravity. Solar heat causes the ices to sublimate and violently release gas as explosions and garden-hose-style jets. The pressure of the solar radiation blows away particles like debris caught in a gale.

Some astronomers think that the fragments now being seen in LINEAR may be the primordial building blocks of the original nucleus, the so-called cometesimals, which theory predicts should be several tens of feet across. The breakup of a comet tells scientists how it was put together in the first place. The cometesimals were built up from micrometer-sized grains of dust as it collected in the early solar system roughly 4.6 billion years ago.

Weaver saw at least a half dozen "mini-comets" with tails on his screen, resembling the shower of glowing fireballs from fireworks. They were clustered in the lance-head tip of an elongated stream of dust and an isolated brighter piece in front of the cluster may be the parent nucleus for the smaller fragments. Hubble's high resolution and sensitivity allowed it to reveal the nuclei as separated bodies at a level of detail never before seen in a disintegrating comet.

Some astronomers find it hard to imagine how an object the size of a mountain could totally disintegrate in only two weeks.

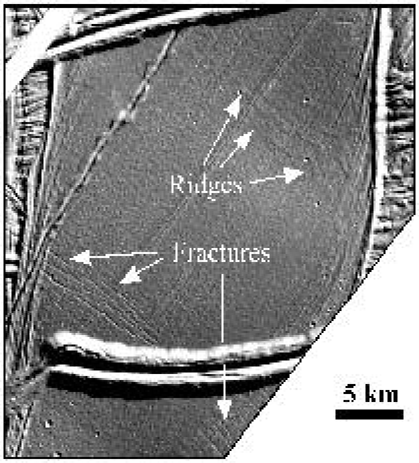
"Actually, I would have been more amazed if Hubble saw no pieces," said co-investigator Carey Lisse, STScI. "The comet's breakup was too violent and fast for it to completely vaporize. How do you pulverize something the size of a mountain?"

Weaver says it will be important for the largest groundbased telescopes to try and see the mini-comets as they spread apart. This may yield further clues on the structure of the original nucleus and the sizes of the remaining fragments.

Some astronomers believe this was Comet LINEAR's first visit to the inner solar system, after traveling for nearly the distance of one light-year (six trillion miles) from the vast comet storehouse called the Oort Cloud. Other astronomers suggest that LINEAR may have been a fragile piece that broke off of a larger comet that visited our solar system more than 10 million years ago.

It's estimated that 20–30% of comets are so fragile they completely disintegrate when they pass the Sun.

Researchers Find Evidence of Folds on Europa



JHU/APL

Researchers have discovered evidence of crests on Europa possibly tens to hundreds of meters high and spaced about 25 kilometers apart.

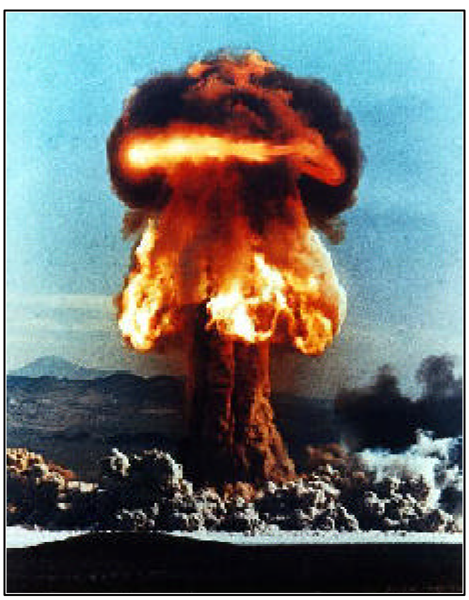
Researchers at The Johns Hopkins University Applied Physics Laboratory and Brown University may have solved a 20-year-old geological mystery surrounding Jupiter's icy moon Europa.

In the August 11, 2000, issue of *Science*, Louise Prockter of APL and Robert Pappalardo of Brown report evidence of "folds" on the moon's frozen surface. The researchers say the mountain-like features — found in three regions — provide the first indication of compression on the fractured Europan crust, and allow unprecedented insight into the history and behavior of the jovian satellite.

"We learned from Voyager images in the late 1970s that there was a lot of extension on Europa — that the surface was pulling apart and a slushy material was moving up through the gaps — but no one could find out how this new material was being accommodated," Prockter said. "Now, we have finally found folds where the icy surface material compresses, and this will help us start to understand how Europa evolved and how it resurfaces."

Prockter and Pappalardo first noticed the folds in high-resolution images of Europa's Astypalaea Linea fracture region, taken by the *Galileo* spacecraft. Near the large fracture zone they spotted fine-scale features that typically occur in fold structures (such as the Appalachian Mountains) on Earth: regional patterns of fractures and small ridges that mark adjacent crests and valleys.

Moon Once Considered for A-Bomb Test



Nuclear detonation, Nevada test site, 1953.

According to a May report by the Associated Press, the U.S. government considered a plan to demonstrate the power of the atomic bomb on the surface of Moon at the height of the Cold War.

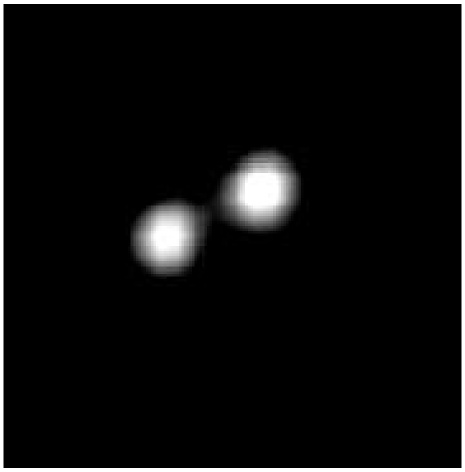
The secret project, known as "A Study of Lunar Research Flights," was considered in the late 1950s but was never implemented.

"Now it seems ridiculous and unthinkable," said physicist Leonard Reiffel, who wrote of the plan in a May letter to *Nature*.

Also revealed in the letter, as well as in two recent biographies, is that a young Carl Sagan worked briefly in the planning stages of the project. The nuclear test was seen as a way to demonstrate U.S. military power and boost the technological patriotism of Americans after the successful Soviet launch of *Sputnik*.

The plan called for a missile to carry a small nuclear device 238,000 miles to the Moon; the device would have been detonated on impact. An atomic bomb was chosen over the heavier, potentially more destructive hydrogen bomb.

According to the AP report, military officials abandoned the idea because of the possibility of danger to those on Earth and concerns about contaminating the Moon.



Double asteroid discovered by team working at the Keck telescope in Hawai'i.

Astronomers Find Double Asteroid

Astronomers announced in October that they had found a large, double asteroid in our solar system. The configuration is a surprise to astronomers, who once thought asteroids were lone objects.

An international team led by William Merline of the Boulder, Colorado, office of the Southwest Research Institute and supported by the National Science Foundation (NSF) and NASA found the asteroid pair. The team used the Keck telescope on Mauna Kea, Hawai'i, which is outfitted with adaptive optics that allow astronomers to examine asteroids and other celestial objects with unprecedented clarity.

Each asteroid in the pair is about 50 miles across. They are separated by about 100 miles, mutually orbiting a spot in space. The asteroid pair was once assumed to be a single body, called Antiope, orbiting the Sun in the outer parts of the asteroid belt between the orbits of Mars and Jupiter.

The team also found a small moon orbiting the large asteroid Pulcova, using adaptive optics on the Canada-France-Hawai'i Telescope on Mauna Kea. Pulcova was the third asteroid observed to have a moon. The first was found in 1993 by the *Galileo* spacecraft, which observed a one-mile-wide moonlet around the 19-mile-diameter asteroid Ida. The Merline team reported the second moonlet a year ago, circling the 135-mile-diameter asteroid Eugenia.

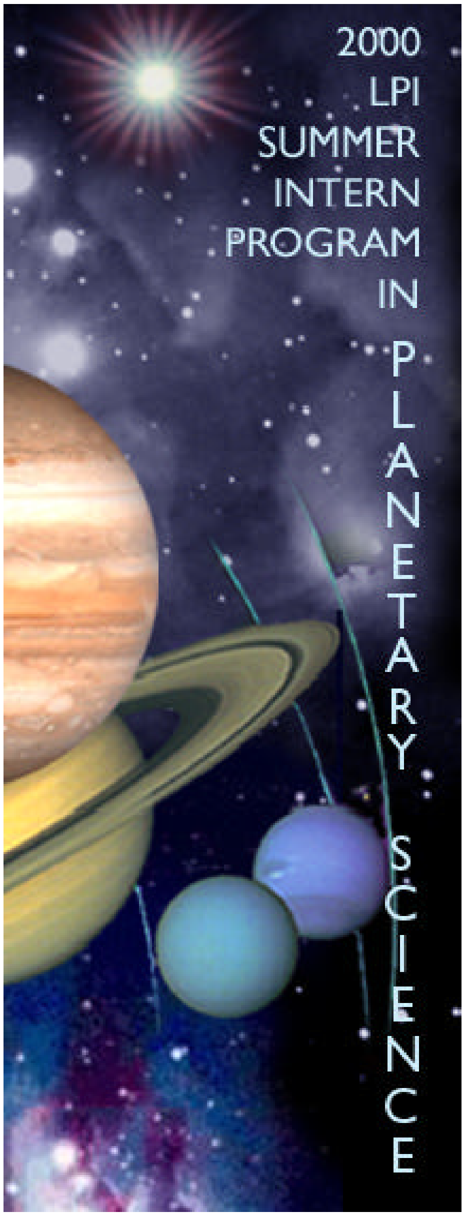
"Preliminary study of about 200 asteroids has turned up only two asteroids with moons (Eugenia and Pulcova) and just one double (Antiope)," Merline said. "It is possible that a few more moonlets might emerge from more sophisticated analysis of the data we have collected." The astronomers expect to find still more configurations and surprises as the survey continues.

"It's getting to be kind of bewildering," said team member Christophe Dumas of the Jet Propulsion Laboratory. "Asteroids were once thought to be single, mountain-like chunks of material, perhaps smashed into 'flying rubble piles' by occasional collisions among themselves."

Asteroidal companions provide vital information about asteroids that has been difficult to obtain. Until now, the best measurements of asteroid mass and density came from deflections of spacecraft flying past an asteroid. Such spacecraft encounters are rare, and deflections of more distant objects (such as other asteroids or planets) by an asteroid's gravity are weak and difficult to measure. But an asteroidal satellite, or twin, is a body whose trajectory is deflected by the asteroid's gravity and forced to orbit around it. The revolution time provides a measure of the body's mass, hence density. Using these techniques, Merline's team earlier found that Eugenia, Pulcova, and Antiope are light bodies, with less density than rocks, even though their sufaces appear dark like rock.

Adaptive optics enable groundbased telescopes to observe asteroids and other small points of light with the same clarity as the Hubble Space Telescope. Until recently, such observations were hindered by distortions caused by the Earth's atmosphere, in much the same way water distorts the view of an underwater object. With the new technique, optical and electronic elements within the telescope sense the distortions and adjust the telescope's output.

The scientists announced the discoveries at the 32nd Annual Meeting of the American Astronomical Society's Division for Planetary Sciences in Pasadena, California.



16th Annual Summer Intern Conference

The Summer Intern Program has been an integral part of the Lunar and Planetary Institute's mission for 24 years. This year marked the sixteenth year that interns have been able to present their projects as part of an intern conference and program. The conference was chaired by Dr. Paul Spudis, LPI Scientist and Deputy Director. What follows are brief abstracts of the presentations. Information about the 2001 Summer Intern Program can be found on the Internet at http://www.lpi.usra.edu/lpiintern.html.

THE STRATIGRAPHY OF LAVA FLOWS IN NORTHERN OCEANUS PROCELLARUM, MOON

Lydia L. Boroughs, *University of Tennessee at Chattanooga*
Advisor: Paul D. Spudis, *Lunar and Planetary Institute*

Northern Oceanus Procellarum, a mare region on the northeastern near side of the Moon, is the area chosen for mapping in this study. Procellarum is the largest maria on the Moon, and occupies most of the western nearside, and has not been previously mapped using the methods described here. Clementine image swaths, obtained in a polar orbit, were used to piece together mosaics of the region of study using the ISIS software from the USGS. Compositional maps of iron and titanium abundance were constructed using the methods described by Lucey et al. and Blewett et al. The resulting images provide maps of Fe and Ti at 200 m/pixel resolution. Using compositional differences obtained from true- and false-color mosaics, as well as the iron and titanium maps, the generalized flow boundaries were located and mapped. The resulting 52 subunits were studied using ISIS software. The regolith covering each flow was measured for composition, carefully avoiding crater ejecta and exposed highlands material. These data provided a preliminary grouping of these units into approximately 20 generalized units, a list that was continually modified and shortened throughout the study with the arrival of new data.

AMMONIA AND PHOSPHINE PHOTOCHEMISTRY OF THE JOVIAN TROPOSPHERE

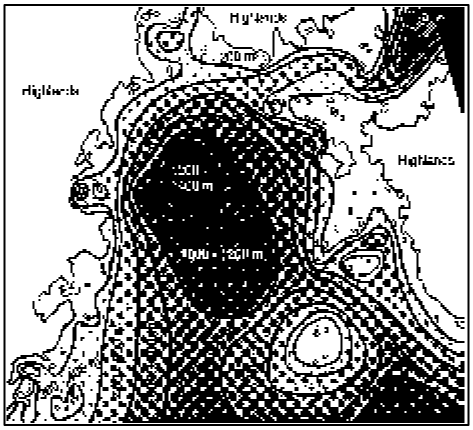
Veronica LaMothe, *State University of New York at Buffalo*
Advisor: Julianne Moses, *Lunar and Planetary Institute*

We investigate ammonia and phosphine photochemistry on Jupiter by developing a one-dimensional steady-state model for the stratosphere and troposphere that accounts for hydrogen, carbon, nitrogen, oxygen, and phosphorus chemistry, vertical eddy diffusion, molecular diffusion, condensation, and radiative transfer (including multiple Rayleigh scattering). This model is unique in that it includes numerous organo-nitrogen reaction schemes and simultaneously models the stratosphere and troposphere. We compare the results of three cases (baseline model, high-acetylene model, and high-eddy-diffusion-coefficient model) with infrared and ultraviolent observations. We find that organo-nitrogen reactions are not very important in Jupiter's troposhere, and the acetylene mole fraction must be less than 10^{-7} in the troposphere in order for HCN to be with observational limits. The tropospheric eddy diffusion coefficient must be less than 10^{-5} cm^2s^{-1}. The implications for chromophores on Jupiter and Saturn are also discussed.

BIOLOGICAL AND INORGANIC WEATHERING OF OLIVINE

Teresa G. Longazo, *Arizona State University*
Advisors: Davis S. McKay, *NASA Johnson Space Center,* and Sue Wentworth, *Lockheed Martin*

This preliminary investigation is to determine how abiotic versus biotic processes affect the weathering of olivine. Two experiments were performed to weather small (< 2 mm) crystals of olivine from San Carlos (in central Arizona). The abiotic experiment involves exposing unweathered grains to hot sterile water and the biotic experiment involves exposing sterile unweathered grains to natural ground water with biota known to affect Columbia River Basalts (in Washington). Perhaps the differences between biologically and inorganically weathered surface textures could be used as biosignatures for future applications to extraterrestrial materials such as martian meteorites.



Isopach map of Northern Oceanus Procellarum showing regional variations in flow depth.

MEASUREMENTS OF EXTENSION AND STRAIN AT ALBA PATERA, MARS, FROM MOLA TOPOGRAPHY

Alexandra L. Dickie, *University of Edmonton*
Advisor: Patrick J. McGovern, *Lunar and Planetary Institute*

New altimetry data from MOLA (Mars Orbital Laser Altimeter) onboard the Mars Global Surveyor spacecraft allow quantitative measurements of fault topography to be made. The purpose of this paper is to present extensional data of the concentric fault zone and use this information to constrain models for the formation and evolution of Alba Patera. Continued investigation of MOLA data have shown that extensional features on the mid-flanks of Alba Patera are characteristic of both single and multiple distribution peaks. Single peak distributions may be the result of one intrusive episode during the evolution of the volcano while a more complex distribution of extension results from multiple episodes of intrusion, some of which may have formed later than the evolution of the Alba Patera edifice itself.

RARE EARTH ELEMENTS AND STRONTIUM PARTITION COEFFICIENTS FOR NAKHLA PYROXENES

Kotaro Oe, *University of Tokyo*
Advisor: Gordon McKay, *NASA Johnson Space Center*

Nakhla, which is generally believed to have come from Mars, is a medium-grained augite-olivine cumulate. Although the composition of its intercumulus melt must preserve important information about petrogenetic processes on Mars, we cannot measure it directly. Various estimates of the major-element composition of this melt ranged widely. Our group had used the approach of finding a melt composition such as those found in Nakhla and resulted in determination of a composition that produce pyroxenes that were an excellent match for the ones in Nakhla. In addition to major and minor elements, it is also important to determine the abundance of key trace elements in the Nakhla melt. In this project, we proposed to experimentally measure pyroxene/melt partition coefficients for Sr and REE that can be confidently used to invert the composition of the Nakhla pyroxenes. We used a synthetic glass of the revised Nakhla melt composition doped with percent levels of REE and Sr as starting material for experiments.

GRAVITY STUDIES OF CORONAE ON VENUS

Kelly Peterson, *University of Kansas*
Advisor: Walter Kiefer, *Lunar and Planetary Institute*

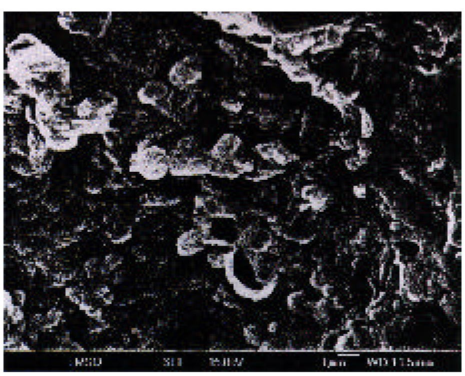
Despite having a similar size and composition, the surface geology of Venus differs greatly from that of Earth. Coronae are unique to Venus and are defined by a circular to elliptical annulus of fractures ranging in size from 60 to 2600 km across and 10 to 150 km wide. Coronae contain volcanic cones, shields and flows and form rises, plateaus, circular rims around depressions or more complex shapes. The apparent topographic evolution and associated fracture patterns of coronae are consistent with formation by hot, rising mantle diapirs. As the diapir moves toward the surface, it creates a topographic high with radial extensional faults, creating corona-like features called novae. Close to the surface the diapir flattens out into an ellipsoid, which creates a plateau. When the diapir cools, the surface relaxes into a rim surrounding a depression. Alternatively, some have argued that delamination and sinking of cool crustal material may contribute to corona formation. Previous gravity studies of coronae have considered only crust and lithosphere properties. The highest concentration of coronae occurs between Bet, Atla, and Themis Regiones (BAT region). Hecate and Parga Chasmata connect Atla Regio to Beta and Themis Regiones respectively. Geologic mapping has determined differing histories for three chains within this larger area. In the south, nine coronae on the western end of Parga Chasma appear to progressively age outward along a three-armed rift. However, the 12 relatively old coronae in a chain stretched between Beta Regio and Kawelu Planitia appear to have formed simultaneously. Situated between these chains, 43 coronae along Hecate Chasma do not have a systematic age progression. In this study, we use spherical harmonic representations of gravity and topography to take a more detailed look at the subsurface structure associated with coronae in these regions.

OCCURRENCE OF FLUID INCLUSIONS IN CM2 CHONDRITES

Joel Saylor, *Case Western Reserve University*
Advisor: Mike Zolensky, *NASA Johnson Space Center*

In the past, fluid inclusions have been found in two H5 chondrites, Monahans and Zag, and in one CI chondrite, Orgueil. These fluid inclusions presented the first glimpse into the possibility of obtaining samples of asteroidal fluid, possibly the water that affected the alteration of many of the C chondrites. For the first time the possibility of doing direct work on this fluid, and thereby placing some constraints on the theory surrounding asteroidal alteration processes, presented itself. In addition this water presents the first possibility of tracing the origins of water on Earth and in our solar system. With all this in mind our investigation had three primary goals. First, to locate fluid inclusions in carbonaceous chondrites. Second, to characterize the minerals and lithologies where the fluid inclusions occur. Finally, to characterize the fluid inclusions themselves to determine whether they result from terrestrial contamination or to characterize the extraterrestrial fluid from which they originated. The first two goals were reached and represent the majority of the information presented here. The final goal could not be achieved in a satisfactory manner for several reasons yet several lines of reasoning point to a possible answer and indicate where further work is needed.

THE RELATIONSHIP BETWEEN HEMATITE AND BACTERIA IN THE GUNFLINT IRON FORMATION FROM ONTARIO, CANADA: IMPLICATIONS FOR THE HEMATITE DEPOSITS ON MARS



Scanning electron microscope image of a chain of four hematite mineralized coccoidal bacteria.

Rachel T. Schelble, *University of New Mexico*
Advisors: Frances Westall, *Lunar and Planetary Institute*, and Carlton C. Allen, *NASA Johnson Space Center*

A fundamental requirement for life is water; thus the main theme in the search for life on Mars in linked with water. The recent discovery of what appears to be large hematite deposits on the equatorial surface of Mars has excited great interest because in most cases, hematite can only be formed in the presence of water. The hematite deposits may therefore be a potential site in the search for past martian life. With this in view, the present study of the interactions between bacteria and hematite in the Gunflint Iron Formation from Ontario, Canada, was undertaken.

THE EFFECTS OF IMPACT ANGLES ON MARTIAN CRATERS USING MOLA DATA

Rachel L. Shanteau, *Bowling Green State University*
Advisor: Robert R. Herrick, *Lunar and Planetary Institute*

An image of a crater demonstrating definite low-angle impact. This is evident in its profiles and by its asymmetrical shape.

The effects of impact angle on impact crater morphology and topography has been studied extensively with experimental work, but little work has been done comparing that work with observations of planetary impact craters. The following study compares experimental work by Gault and Wedekind with the topography and morphology of martian craters. Gault and Wedekind found that no significant elongation in craters occurred for impact angles >15°. In reference to the ejecta blanket, they found no distinct difference in the blanket's axial symmetry until an angle <45°. As the impact angle decreases with respect to horizontal, a forbidden zone appears uprange and then spreads to downrange. A butterfly wing ejecta pattern occurs from near grazing impacts.
The purpose of this study is to compare these experimental results to topography and images of martian craters. From there comparisons can be made with a study from Bottke et al. that uses both topographic data and the lab experiments, a study such as Garvin et al. using topographic data, and morphology studies such as Strom et al.

SURFACE COMPOSITION OF MARS: EXAMINATION OF SYRTIS MAJOR USING THERMAL INFRARED DATA

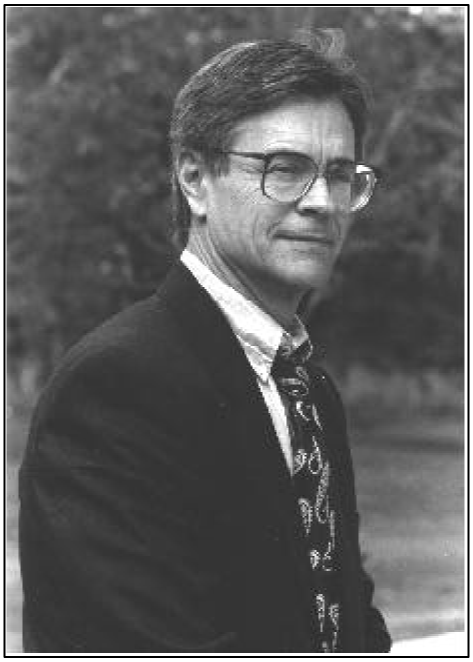
Jennifer Ward, *Colgate University*
Advisor: Laurel Kirkland, *Lunar and Planetary Institute*

Syrtis Major is one of the prominent low-albedo regions of Mars, and is believed to be a low-relief shield volcano. However, it has an unexpectedly moderate thermal inertia, implying the presence of coarse-grained material. Mustard et al. assert that both low- and high-calcium pyroxenes compose the dark region of Syrtis Major. Bandfield et al. cite two likely compositions for the low-albedo regions of Mars: (1) a clinopyroxene and plagioclase feldspar dominated basalt and (2) a volcanic glass and plagioclase feldspar dominated andesite. They propose that NW Syrtis Major has an andesitic composition, while the majority of Syrtis is in the basaltic regime. Many believe that the dark regions are composed of more coarse particles than the bright regions, with Syrtis in particular containing sand-sized particles. The purpose of this project is to test the assertions described above.

PHASE RELATIONS OF A MODEL MARTIAN MANTLE AT 5 GPa

Abigail A. Wasserman, *Princeton University*
Advisor: Carl Agee, *NASA Johnson Space Center*

Relationships between major-element ratio pairs show that ordinary chondrite compositions like Homestead L5 are good starting points from which the array of martian compositions (SNC meteorites and Pathfinder rocks) can be generated via garnet fractionation from an early martian magma ocean. The bulk silicate composition of Homestead is also similar to currently used model martian compositions. Accordingly, Homestead was chosen as the starting material for these experiments. The two specific objectives pursued in this stage of the project were (1) to begin exploring the melting relations of Homestead L5 and (2) to test the garnet fractionation hypothesis for generating the Mars composition array. Good progress was made on the former objective, and one experiment was successfully completed that helps address the latter.



David C. Black

David Black named president of USRA

The USRA Board of Trustees has announced the selection of LPI Director Dr. David C. Black as the fourth president of the Universities Space Research Association. Dr. Black has been director of the USRA's Lunar and Planetary Institute in Houston since 1988.

Dr. Black received his Ph.D. in physics from the University of Minnesota in 1970. Between 1970 and 1975, he served in various capacities at NASA's Ames Research Center, including Chief of the Theoretical Studies Branch, Deputy Chief of the Space Science Division, and the first Chairman of the Ames Basic Research Council. Dr. Black was selected as the first Chief Scientist for the Space Station Program at NASA Headquarters in 1985. He returned to NASA Ames in 1987 as the Chief Scientist for Space Research. In 1988, he was selected as director of USRA's Lunar and Planetary Institute. Last year, he accepted additional responsibilities for USRA as Vice-President for Space Science.

During his service with the government and with USRA, Dr. Black has maintained close contact with the university community. He spent an academic year as a Visiting Professor at the University of London in 1974–1975. He has been a Consulting Professor at Stanford University and is currently an Adjunct Professor of Space Physics and Astronomy at Rice University.

Dr. Black is an internationally recognized researcher in theoretical astrophysics and planetary science, specializing in studies of star and planetary system formation. He has also done pioneering experimental research involving the isotopic composition of noble gases in meteorites. He is a leader in the current effort to search for and study other planetary systems.

Dr. Black is a member of the Editorial Board of *Astrophysical Letters and Communication* and has authored or coauthored more than 100 articles for scientific journals. He served as lead editor for *Protostars and Planets II*, published by the University of Arizona Press. In addition to his scientific and academic work, Dr. Black has volunteered as a coach for Special Olympics for the past eight years and also serves on the Board of the Clear Creek Education Foundation.

New Electronic Publication

The *Solar System Exploration Newsletter* is now available on line at http://solarsystem.nasa.gov/results/newsletter/newslet.html. The SSE Newsletter is published on line by the Science Director for Exploration of the Solar System in NASA's Office of Space Science to inform the science community about activities and plans at NASA Headquarters.

Photo by Debra Reub

Student Visitor

LPI scientist Renu Malhotra, right, spends a few moments instructing Tavish C. Kelly, a 10-year-old student interested in astrophysics. Kelly spent several days at the Lunar and Planetary Institute this summer, meeting with LPI scientists Malhotra, Julie Moses, Walter Keifer, and Allan Treiman. Malhotra has since taken a position at the Department of Planetary Sciences at the University of Arizona.

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Brian Anderson, Editor

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The Bulletin welcomes the submission of articles and essays dealing with issues related to planetary science and exploration. Please send articles or announcements to: B. Anderson, 3600 Bay Area Boulevard, Houston TX 77058-1113.

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CALENDAR 2001

FEBRUARY

21–23

Forum on Innovative Approaches to Outer Planetary Exploration, 2001–2020, Lunar and Planetary Institute, Houston, Texas
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2143; fax: 281-486-2160
E-mail: cloud@lpi.usra.edu
http://www.lpi.usra.edu/meetings/outerplanets2001/

MARCH

12–16

32nd Lunar and Planetary Science Conference, Houston, Texas.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2125
E-mail: simmons@lpi.usra.edu
http://www.lpi.usra.edu/meetings/lpsc2001/

APRIL

22–25

Division on Dynamical Astronomy, American Astronomical Society, Lunar and Planetary Institute, Houston, Texas.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2151; fax: 281-486-2160
E-mail: taylor@lpi.usra.edu

24–27

Origins of Stars and Planets: The VLT View, European Southern Observatory Workshop, Garching, Germany.
Contact: European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748, Garching, Germany.
Phone: 49-89-320-060; fax: 49-89-3200-6480
E-mail: starplan@eso.org

MAY

20–24

Eleventh Annual V. M. Goldschmidt Conference, Roanoke, Virginia.
Contact: Goldschmidt 2001, PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2125
E-mail: simmons@lpi.usra.edu
http://www.lpi.usra.edu/meetings/gold2001/

AUGUST

6–10

Conference on the Geophysical Detection of Subsurface Water on Mars, Lunar and Planetary Institute, Houston, Texas.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2151; fax: 281-486-2125
E-mail: taylor@lpi.usra.edu
http://www.lpi.usra.edu/meetings/geomars2001/

SEPTEMBER

10–14

64th Meteoritical Society Meeting, Rome, Italy.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2151; fax: 281-486-2160
E-mail: taylor@lpi.usra.edu
http://www.lpi.usra.edu/meetings/metsoc2001/

OCTOBER

4–5

Mercury: Space Environment, Surface, and Interior Workshop, Chicago, Illinois.
Contact: Publications and Program Services Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058-1113.
Phone: 281-486-2151; fax: 281-486-2160
E-mail: taylor@lpi.usra.edu
http://www.lpi.usra.edu/meetings/mercury01

20–28

Martian Highlands Field Conference, Death Valley, California.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058-1113.
Phone: 281-486-2123; fax: 281-486-2160
E-mail: perry@lpi.usra.edu

NOVEMBER

5–8

Fall Geological Society of America Meeting, Boston, Massachusetts.
Contact: The Geological Society of America, P.O. Box 9140, Boulder, CO 80301-9140.
Phone: 303 447-2020 or 1-800-472-1988
Fax: 303-447-0648
E-mail: meetings@geosociety.org

CALENDAR 2001

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21–23

Forum on Innovative Approaches to Outer Planetary Exploration, 2001–2020, Lunar and Planetary Institute, Houston, Texas
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2143; fax: 281-486-2160
E-mail: cloud@lpi.usra.edu
http://www.lpi.usra.edu/meetings/outerplanets2001/

MARCH

12–16

32nd Lunar and Planetary Science Conference, Houston, Texas.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2125
E-mail: simmons@lpi.usra.edu
http://www.lpi.usra.edu/meetings/lpsc2001/

APRIL

22–25

Division on Dynamical Astronomy, American Astronomical Society, Lunar and Planetary Institute, Houston, Texas.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2151; fax: 281-486-2160
E-mail: taylor@lpi.usra.edu

24–27

Origins of Stars and Planets: The VLT View, European Southern Observatory Workshop, Garching, Germany.
Contact: European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748, Garching, Germany.
Phone: 49-89-320-060; fax: 49-89-3200-6480
E-mail: starplan@eso.org

MAY

20–24

Eleventh Annual V. M. Goldschmidt Conference, Roanoke, Virginia.
Contact: Goldschmidt 2001, PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2158; fax: 281-486-2125
E-mail: simmons@lpi.usra.edu
http://www.lpi.usra.edu/meetings/gold2001/

AUGUST

6–10

Conference on the Geophysical Detection of Subsurface Water on Mars, Lunar and Planetary Institute, Houston, Texas.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2151; fax: 281-486-2125
E-mail: taylor@lpi.usra.edu
http://www.lpi.usra.edu/meetings/geomars2001/

SEPTEMBER

10–14

64th Meteoritical Society Meeting, Rome, Italy.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058-1113.
Phone: 281-486-2151; fax: 281-486-2160
E-mail: taylor@lpi.usra.edu
http://www.lpi.usra.edu/meetings/metsoc2001/

OCTOBER

4–5

Mercury: Space Environment, Surface, and Interior Workshop, Chicago, Illinois.
Contact: Publications and Program Services Department, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058-1113.
Phone: 281-486-2151; fax: 281-486-2160
E-mail: taylor@lpi.usra.edu
http://www.lpi.usra.edu/meetings/mercury01

20–28

Martian Highlands Field Conference, Death Valley, California.
Contact: PPSD, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058-1113.
Phone: 281-486-2123; fax: 281-486-2160
E-mail: perry@lpi.usra.edu

NOVEMBER

5–8

Fall Geological Society of America Meeting, Boston, Massachusetts.
Contact: The Geological Society of America, P.O. Box 9140, Boulder, CO 80301-9140.
Phone: 303 447-2020 or 1-800-472-1988
Fax: 303-447-0648
E-mail: meetings@geosociety.org